Senior Thesis

The Regional Oceanography of the Kara Sea and Examination of core C-93/134 from the East Novaya Zemlya Trough, Russia

by

Laura J. Walker

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Approved by:

Dr. Steve Forman

Abstract

The Kara Sea is a shallow epicontinental sea located in the Russian Arctic. Dominant currents of the Kara Sea change seasonally; dense bottom waters in the winter and surface riverine controlled currents in summer. North Atlantic derived intermediate waters enter the Kara Sea through deep troughs. The East Novaya Zemlya Trough runs roughly parallel and east of the Novaya Zemlya archipelago, the location of core C-93/134. Magnetic susceptibility, bulk densities, color, continuous laminations, and sand, silt and clay percentages reflect the homogeneity of depositional environment of unit 1A. Unit 1B is interpreted as a turbidite or mass slumping event due to the anomalous percentage sand and biota. Fecal pellets, present in the upper 40 cm of the core, result in the possible misrepresentation of sand percentages for the intervals sampled in the upper 40 cm. Sedimentation in the East Novaya Zemlya Trough is dominated by pelagic input and at selected times gravity driven processes.

Introduction

The eperic Kara Sea is located in the Russian Arctic, over the western Asiatic Arctic continental shelf (Andrew and Kravitz, 1974). The Kara Sea, similar to other shallow Arctic Seas, is a source of dense bottom water, resulting from sea ice formation. The dense bottom waters are an important driving mechanism of Arctic Ocean circulation. The large volume of year round sea ice cover on the Kara Sea has limited scientific investigation. A greater understanding of the circulation of the Kara Sea is needed to further understand Arctic Ocean circulation. This paper describes what is known of the modern oceanography of the Kara Sea and examines the lithology and other physical properties of C-93/134 a core recovered from the East Novaya Zemlya Trough.

Regional Oceanography of the Kara Sea

The Kara Sea has a surface area of 851,000 km^2 and a volume of 111,000 km^3 (Andrew and Kravitz, 1974). The mean water depth is 90 m, but the maximum water depth is greater than 640 m (Andrew and Kravitz, 1974). Only 15% of the Kara Sea is deeper than 200 m, which accounts mostly for the East Novaya Zemlya Trough, the St. Ann Trough and the Voronin Trough (Andrew and Kravitz, 1974). Several bodies of land surround the Kara Sea: the Yamal and Taymyr Peninsulas to the south and east, Novaya Zemlya to the west and Severnaya Zemlya to the north.

Seasonal Variations

Seasonal variations of dominant currents reflect a sea ice formation, sea ice melting and river discharge, and greatly influence the Kara Sea (Levitan et. al., unpublished and Andrew and Kravitz, 1974). Sea ice begins to form on the average in September and begins to melt in June; maximum ice thicknesses are 1.5 m (Levitan et. al., unpublished). Winter sea ice formation in the Kara Sea, similar to other Arctic shelves, results in high salinity, dense bottom waters (Forman and Johnson, 1995). The density driven deep water flows north into the Arctic Ocean, often following sea floor bathymetry. In the Kara Sea, the dense bottom waters flow north along the eastern side of the St. Anna Trough (Andrew and Kravitz, 1974). The winter season of the Kara Sea, dominated by sea ice cover, has been described as a reverse estuary due to the outflow of high density saline bottom water (Forman and Johnson, 1995).

Fresh water from Siberian Rivers, during the months of June and July, flood the Kara Sea shelf (Andrew and Kravitz, 1974). The discharge of the Ob, Yenisey and Lena Rivers supply 70% of the river water that flow into the Arctic Ocean (Forman and Johnson, 1995). The summer seasons, June and July, account for 90% of the annual volume of river water that drain into the Arctic, often under remaining sea ice (Forman and Johnson, 1995). Therefore, surface currents of the Kara Sea are strongest during the warmer summer months due to discharge of Siberian rivers and decreasing volume of ice (Andrew and Kravitz, 1974 and Forman and Johnson, 1995).

Surface Circulation

A cyclic gyre dominates the surface circulation of the western half of the Kara Sea with an average current velocity of 10 cm/s (see Figure 1)(Levitan et. al., unpublished and Andrew and Kravitz, 1974). The northward current begins at the Ob River delta, moves north and west towards Novaya Zemlya, then south along the eastern coast of Novaya Zemlya and completes the circle by moving west and north along the Yamal Peninsula (Andrew and Kravitz, 1974). Northward and eastern currents from the Yenisey River delta dominate surface circulation of the eastern half of the Kara Sea. The currents move toward the Arctic Ocean with velocities as fast as 60 cm/s (Levitan et. al., unpublished and Andrew and Kravitz, 1974).

Atlantic Derived Water

Year round sea ice coverage, large volumes of river water during the summer, and the location of Novaya Zemlya restrain warm surface Atlantic water from entering the Kara Sea. A small amount of surface Atlantic water may enter the Kara Sea around the north-eastward tip of Novaya Zemlya from the Barents Sea (Hanzlick and Aagaard, 1980). Although minimal amounts of surface Atlantic derived water enters the Kara Sea, Atlantic derived waters at intermediate depth, 150 to 400 m, may enter through the St. Anna Trough, the Voronin Trough, and the passage between Novaya Zemlya and Franz Josef Land (Andrew and Kravitz, 1974 and Levitan et. al., unpublished) The intermediate water is an important heat source for melting sea ice in the Kara Sea (Hanzlick and Aagaard, 1980).

Sedimentary Facie Zones of the Kara Sea

Categorization and divisions of a natural occurring phenomenon can be helpful to scientists for organizational purposes, but may also be considered arbitrary and limiting. One method of categorizing the Kara Sea, described by Levitan et. al. (unpublished) is based on bathymetry, physical oceanography, grain size, and mineral and chemical compositions. The divisions are the Western Zone (I) and the Ob-Yenisey Zone (II). The preceeding explanation is limited to Facie Zone (I), due to focused interest in the Western Zone of the Kara Sea, the location of core C-93/134.

Levitan et. al. divide the Western Zone (I) into two subzones: I-A, sediments of depression, and I-B, sediments of the Western Kara Rise. Both subzones have insignificant sand contents, usually from 5 to 7% (Levitan et. al. unpublished). Sediment supply in the Western Facie Zone is from the Siberian land mass, Ural Mountains and most importantly from Novaya Zemlya (Levitan et. al., unpublished).

Subzone I-A, defined as areas of depression or >100 m water depth, encompasses the East Novaya Zemlya Trough (Levitan et. al., unpublished). Strong currents, of the circular gyre previously described, influence sedimentation, which leads to relatively well sorted sediments, small amounts of coarse material, and larger amounts of clayey mud (Levitan et. al., unpublished). The sedimentation in subzone I-A is dominated by pelagic process (Levitan et. al., unpublished). Subzone I-B is an area with water depth of <100 m; most of the Western Kara Sea Rise (Levitan et. al., unpublished). Subzone I-B has a higher concentration of coarse material. Sedimentation is of a pelagic nature, but also effected by winnowing, due to stronger bottom currents associated with shallower water depths (Levitan et. al., unpublished).

The East Novaya Zemlya Trough

The East Novaya Zemlya Trough runs roughly parallel and east of the Novaya Zemlya archipelago located in the Kara Sea. Complex bottom relief, isolated depressions, and water depth of 350 to 500 m are characteristic of the Trough (Dunayev, 1991). At the 200 m isobath of the East Novaya Zemlya Trough the average width is 80 to 100 km, but it ranges from 20 to 120 km (Dunayev, 1991).

Seismic data indicates the East Novaya Zemlya Trough is floored by Cretaceous-Paleogene(?) rock of terrigenous and marine origin (Dunayev, 1991 and Kulakov, 1988). Unconsolidated sediments up to 300 m thick are late Pleistocene-Holocene. The inferred depositional environment of the sediments is of glacial and marine origin (Dunayev, 1991 and Kulakov, 1988).

Examination of C-93/134 from the East Novaya Zemlya Trough

Methods

The core, C-93/134, was sampled every 20 cm and additional intervals at 12 cm, 30 cm, 90 cm, 105 cm, 110 cm, and 115 cm, for sedimentary analysis (see appendix). Samples were 10 cc except at 3.5 cm, which had a volume of 5 cc. The samples were weighed for wet bulk density, oven dried at 50°c, and weighed again for dry bulk density. Diluted sodium hexemataphoshpate was used as a dispersant in preparation for wet sieving. The samples were wet sieved at 63µm for sand, silt, and clay percentages. Additional larger samples weighing between 78.6 g and 106.5 g, were taken about every 20 cm for foram analysis and radio carbon dating for time control.

The sand fractions, >63µm, were dried and weighed. The silt and clay fractions, <63µm, were measured using settling properties derived from Stoke's Law. The methods for sampling times, temperatures and depths were followed as outlined by Gale and Hoare, (1991; p.89).

Two additional 5 cc samples were taken at 8 cm depth to re-examination the sand, silt and clay percentages because of the presence of fecal pellets. One sample was treated with 30% H_2O_2 for 12 days; the time needed for no further reaction between the H_2O_2 and the fecal pellets within the sample to occur. Both sand fractions were dried and weighed and the silt and clay percents of the samples were assessed using the previously mentioned pipette analysis (see Figure 2).

Results

Magnetic Susceptibility

Magnetic susceptibility (MS) is used as a relative measurement of change in grain size or magnetic mineral content. MS corrected data of core C-93/134 taken at 2 cm intervals vary slightly downcore (see Figure 3 and Table 1) (Operational Manual Bartington Instruments Ltd., 1990). The lack of variation of the MS data reflects the homogenaety of the core. The values range from 10.8 to 41.4 SI units, excluding values due to the edge effect at core breaks and the core catcher.

Wet and Dry Bulk Densities

Both the wet and dry bulk densities vary slightly downcore, which also indicates the homogeneity of unit 1A (see Figure 3 and Table 2). The average wet bulk density is 1.69 g/cc ±0.11 and the average dry bulk density is 0.93 g/cc ±0.10. Unit 1B has slightly larger wet and dry density values 1.80 g/cc and 1.16 g/cc, respectively, due to the higher sand content.

Sand, Silt and Clay Percentages

Sand, silt and clay percentages of unit 1A have relatively little change (see Figure 4 and Table 3). The sand values for unit 1A average 10.5 ± 3.4%. Unit 1B sand content is 46.2%. Silt percentages increase and decrease proportional to the sand percents. The average silt percentage, excluding unit 1B, is 37.3 ±6.5%. Clay percents tend to vary more than sand percents averaging 52.2 ±6.1%. Clay percentages are indirectly proportional to the sand percentage, intervals with high sand percents have relatively low clay percents and vise-versa. The sample taken at 12 cm has 13.1% sand and 38.4% clay. At 30 cm, the sand is only 4.9% and clay accounts for 50.7%. In summary, sand and clay percents are inversely proportional and sand and silt percents are directly proportional.

Fecal Pellets

Sample 8A has sand, silt and clay percents of 6.7%, 37.3%, and 56.0% respectively (see Figure 2). Sample 8B, had an initial dry weight of 3.90 g, but a weight of 3.44 g after the 30% H_2O_2 treatment. Twelve percent of the original sample was dissolved by the H_2O_2. Sand, silt and clay percents of 8B after the H_2O_2 are 3.2%, 36.0% and 60.8%.

Discussion and Interpretation of Data

Present water depth at the location of the core is 341 m, relatively deep for the Kara Sea. The core was taken at 72°17.995′ latitude and 57°38.338′ longitude. Although no age control has been obtained, it is estimated that the sediments of the entire core were deposited in the Holocene.

Core C-93/134 has two lithologic units 1A and 1B. Unit 1A is from 0 to 106 cm and 111 to 248 cm. Unit 1B is from 106 to 111 cm. Unit 1A is a dark grayish-brown clay with dark-brown sand to silt sized particles (see Figure 5). The upper 19 cm of unit 1A is oxidized and bioturbated. Unit 1B is distinguishable due to the anomalous high sand content although it is the same color as unit 1A.

The depositional environment of unit 1A has remained somewhat constant throughout the core based on MS, bulk densities, grain size, color and continuous laminations. The low energy environment of the East Novaya Zemlya Trough supplies nutrients for biota consisting of forams, mollusks, and ostrocodes. The high clay percentages and low sand percentages indicate pelagic sedimentation. Three drop stones in the core are evidence of seasonal sea ice coverage, or transit of icebergs. Sedimentation rates are thought to be high due to the close source of material, the Novaya Zemlya archipelago.

The depositional environment of unit 1B is interpreted as a redepositional event, a turbidite, mass slumping, or less likely iceberg discharge. This interval contains shells of infaunal bivalve molluscs (mainly *Yoldiella*), and sessile epifaunal organisms: fragments of *Bryozoa* and large foraminifers (*Cibicides, Cornuspiroids, Cyclogyra*). This faunal composition suggests redeposition from shallower depths (<100-150 m) (Polyak, L., personal communication).

The presence of fecal pellets is evident in the upper 40 cm of the core. Fecal pellets are the excreted waste of organismsm and are important transporters of nutrients and particles from the surface to the bottom of the water column. The fecal pellets are >63 μm in diameter. Therefore the sand percentages represented in figure 2, for samples containing fecal pellets, are misrepresented. The actual sand percentages without the fecal pellets would be smaller than the values on Figure 4 and Table 3. Below 40 cm fecal pellets are insignificant and the sand percents of Figure 2 are correct.

Conclusion

Oceans cover 71% of the surface of the Earth. Understanding ocean circulation is crucial for modelling the interaction of the many Earth systems of the past, present and future. Ocean sediment cores are an excellent record of past depositional environments. Knowledge of past depositional environments can help scientists predict future environments. Sediment cores were sampled from the Kara Sea because it plays an important role in the circulation of the Arctic Ocean due to the formation of dense bottom waters. The dense bottom waters are one driving mechanism of the circulation of the Arctic Ocean. Conclusions drawn from the examination of core C-93/134 indicate that sedimentation in the East Novaya Zemlya Trough was continuous and dominated by pelagic inputs and gravity driven processes at the sea bed.

Acknowlegdements

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References

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Polyak, L., personal communication, 4-95.

Figure 1. The surface and intermediate currents of the Kara Sea (Andrew and Kravitz, 1974).

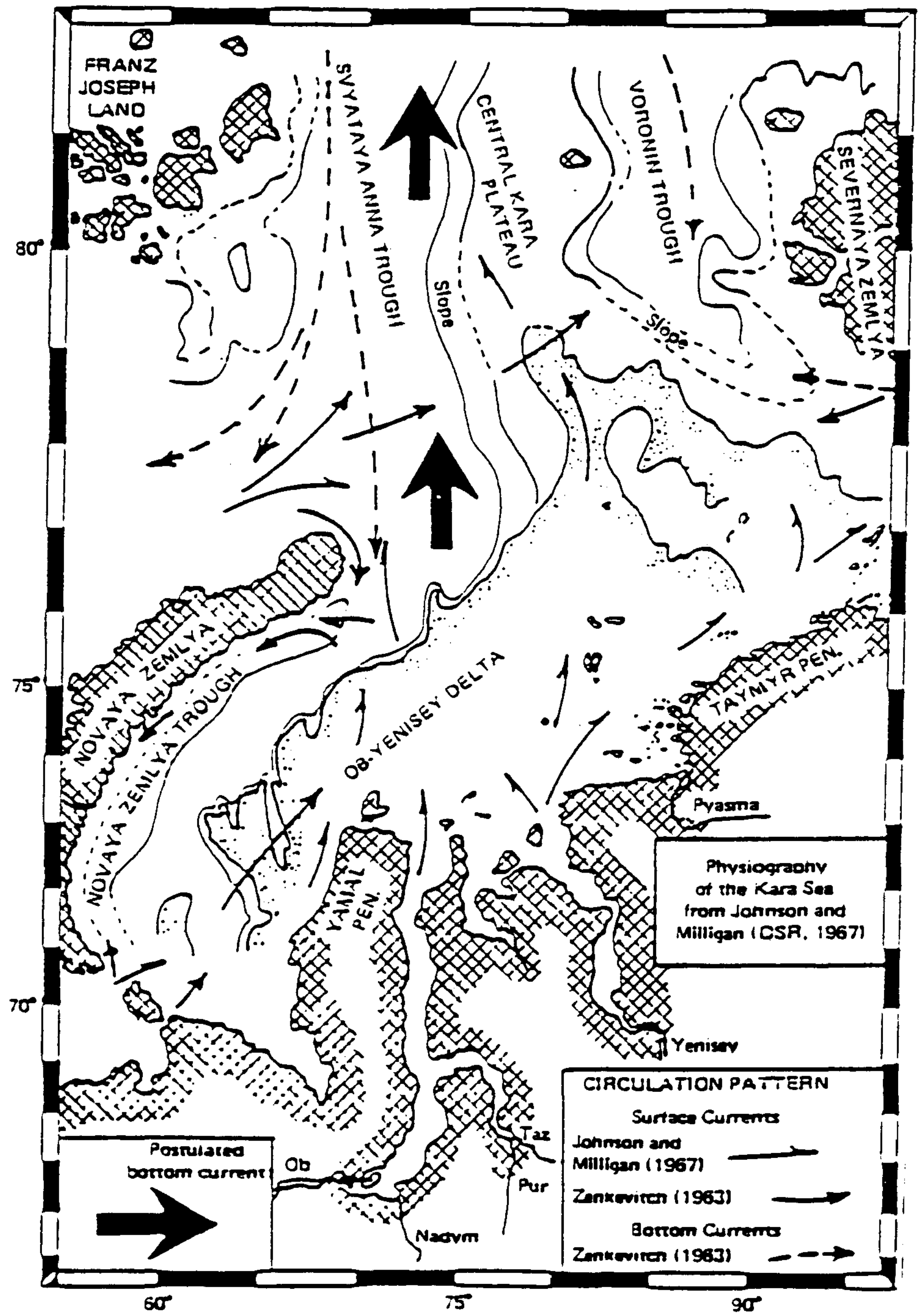


Figure 2 **Fecal Pellets**

	8A	8B (after H2O2)
sand (g)	0.28	0.11
silt (g)	1.55	1.24
clay (g)	2.33	2.09
total (g)	4.16	3.44
% sand	6.7	3.2
% silt	37.3	36
% clay	56	60.8

Total organic carbon of sample 8B is 12%

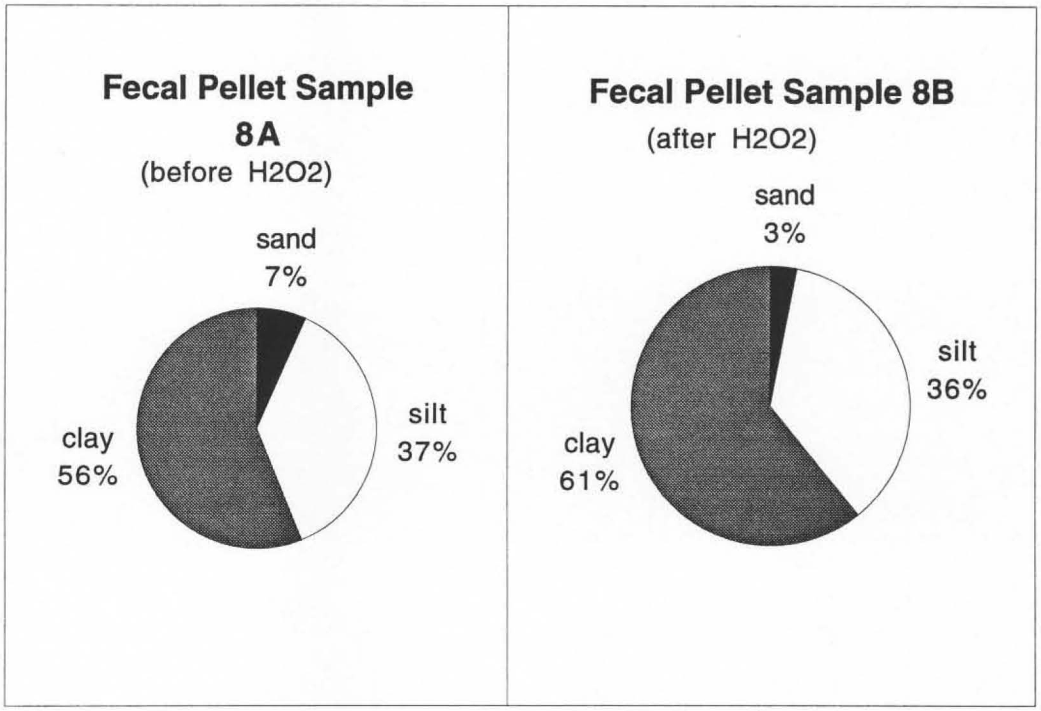


Figure 3

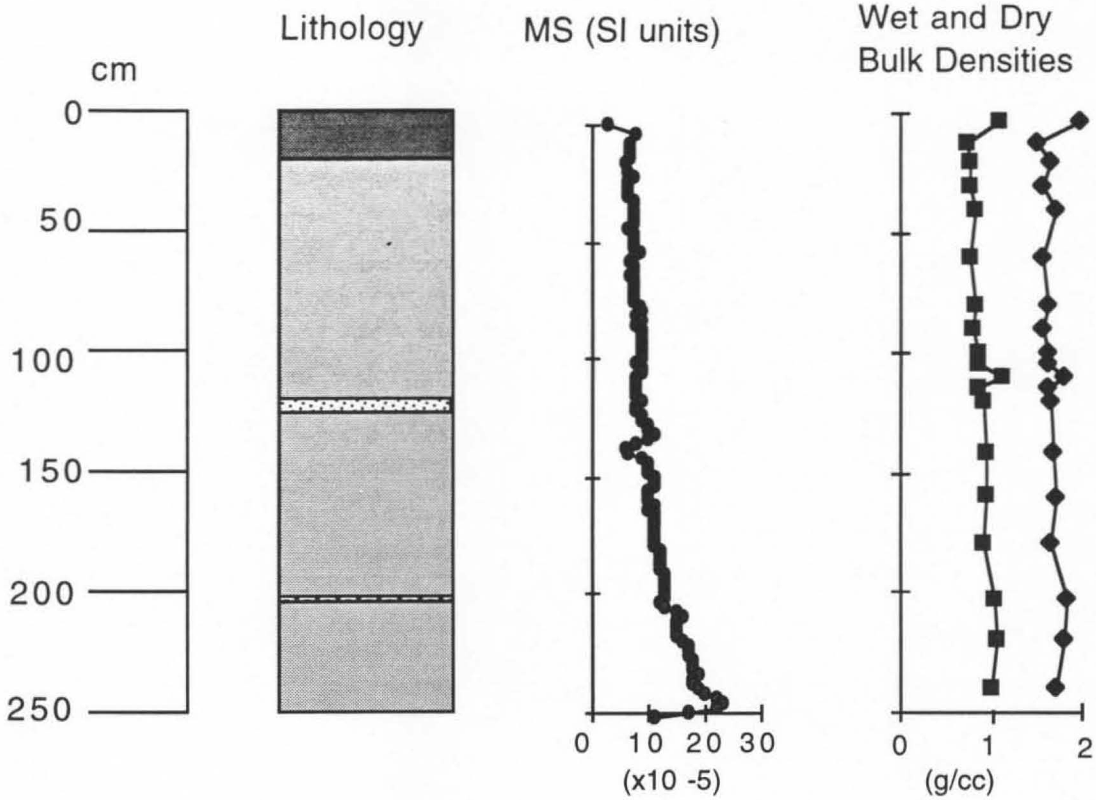

Lithology
MS (SI units)
Wet and Dry
Bulk Densities
cm
0
50
100
150
200
250
0
10
20
30
(x10 -5)
0
1
2
(g/cc)

Figure 4 Sand, Silt and Clay Percentages

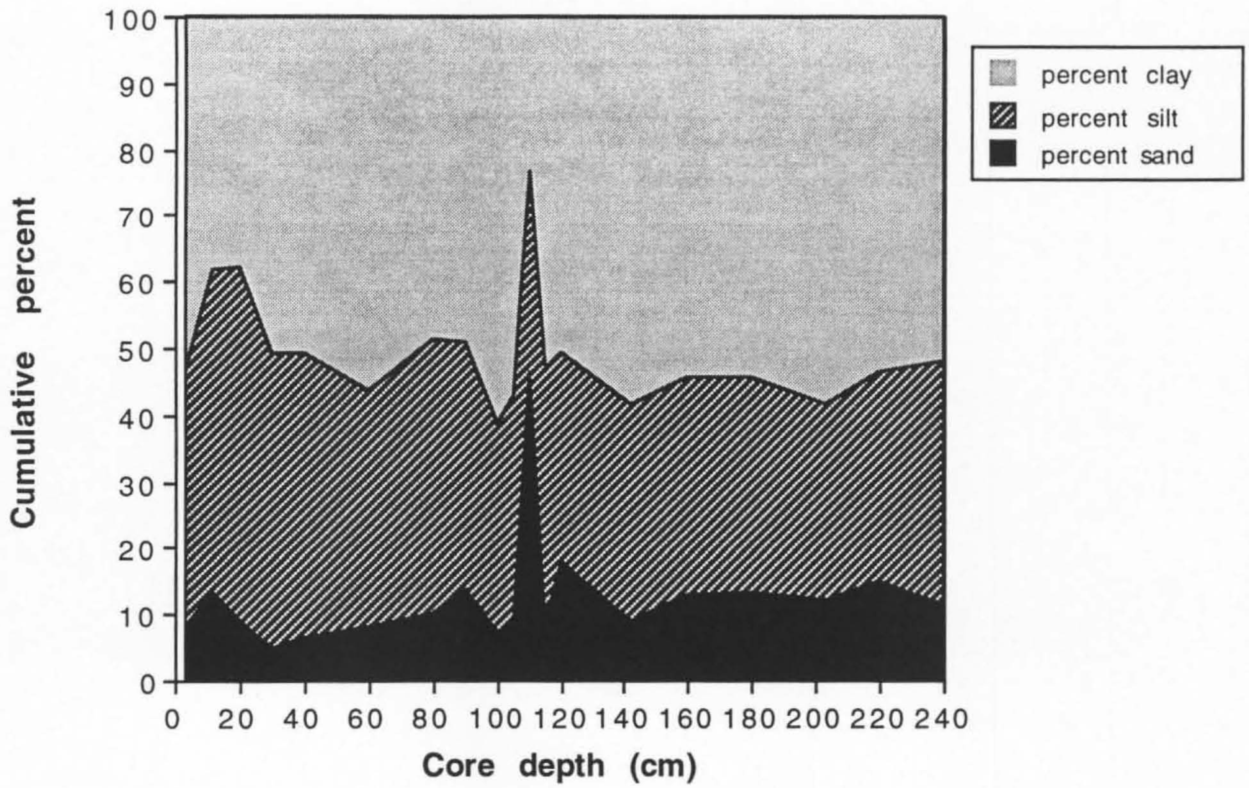
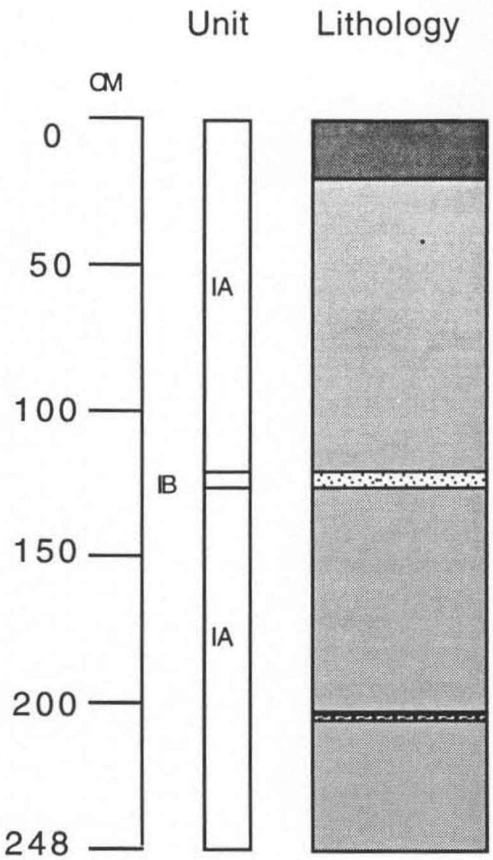


Figure 5 **C-93/134** **From the East Novaya Zemlya Trough**



Munsell Color Index	Lithologic Description
Hue 2.5 Y 4/2 and 10 YR 3/2	0-19cm oxidized layer dark grayish brown clay with very dark grayish brown clay, bioturbated
Hue 2.5 Y 4/2	19-106 cm dark grayish brown clay with dark brown silt sized particles, finely laminated
Hue 2.5 Y 4/2	106-111 cm dark grayish brown clay with increase of sand content
Hue 2.5 Y 5/2	111-248 cm dark grayish brown clay with dark brown silt sized particles, finely laminated, with 1 cm band of increased sand content at 203 cm

Interpreted
Depositional
Environment

0-106cm and 111-248 cm
low energy environment
pelagic sedimentation
seasonal ice coverage

106-111cm
turbidite or mass slumping
event

Drop stone information

90 cm - black drop stone 0.13 g

190 cm - gray drop stone 15.0 g

231 cm - light brown
drop stone .0.63 g

Table 1 Magnetic Susceptibility (SI Units)

MS (x10 -5 SI units	Core Depth (cm)	correction amt.
5.4	0	0
14.4	4	2
12.6	8	1
12.6	10	1
12.6	12	1
12.6	14	1
10.8	16	1
11.34	20	0.3
13.32	22	0.4
11.52	24	0.4
11.52	26	0.4
11.52	28	0.4
11.7	30	0.5
13.5	32	0.5
13.5	34	0.5
13.5	36	0.5
13.5	38	0.5
13.5	40	0.5
13.5	42	0.5
11.7	44	0.5
13.68	46	0.6
13.68	48	0.6
13.68	50	0.6
13.86	52	0.7
15.66	54	0.7
13.86	56	0.7
12.06	58	0.7
13.86	60	0.7
13.86	62	0.7
12.06	64	0.7
13.86	66	0.7
13.86	68	0.7
13.86	70	0.7
13.86	72	0.7
13.86	74	0.7
13.86	76	0.7
15.66	78	0.7
15.84	80	0.8
14.04	82	0.8
15.84	84	0.8
14.04	86	0.8
15.84	88	0.8
15.84	90	0.8
15.84	92	0.8
15.84	94	0.8
15.84	96	0.8
15.84	98	0.8
15.84	100	0.8
14.22	102	0.9
16.02	104	0.9
16.02	106	0.9
14.22	108	0.9
14.22	110	0.9
14.22	112	0.9
14.22	114	0.9
14.22	116	0.9
16.02	118	0.9
14.22	120	0.9
14.22	122	0.9
16.02	124	0.9
16.02	126	0.9
17.82	128	0.9

MS (SI units)	Core Depth (cm)	correction amt.
17.82	130	0.9
19.8	132	1
18	134	1
14.4	136	1
10.8	138	1
11.88	140	-0.4
16.2	142	0
18	144	0
18	146	0
18	148	0
19.8	150	0
19.8	152	0
19.8	154	0
18	156	0
18	158	0
18	160	0
19.8	162	0
18	164	0
19.8	166	0
19.8	168	0
19.8	170	0
19.8	172	0
19.8	174	0
19.8	176	0
19.8	178	0
19.8	180	0
21.6	182	0
21.6	184	0
21.6	186	0
21.6	188	0
21.6	190	0
23.4	192	0
23.4	194	0
23.4	196	0
23.4	198	0
23.4	200	0
23.4	202	0
21.6	204	0
23.4	206	0
27	208	0
28.8	210	0
27	212	0
27	214	0
27	216	0
27	218	0
28.8	220	0
30.6	222	0
30.6	224	0
30.6	226	0
32.4	228	0
32.4	230	0
32.4	232	0
34.2	234	0
32.4	236	0
32.4	238	0
34.2	240	0
36	242	0
39.6	244	0
41.4	246	0
39.6	248	0
30.6	250	0

Table 2 Wet and Dry Bulk Densities

core dpth(cm)	bulk density wet (g/cc)	bulk density dry (g/cc)
3.5	1.98978	1.1392
12	1.52644	0.78475
20	1.66964	0.81219
30	1.57599	0.80511
40	1.71604	0.86179
60	1.57706	0.81927
80	1.6405	0.88256
90	1.58285	0.84958
100	1.6262	0.89492
105	1.6429	0.89859
110	1.80467	1.16471
115	1.64651	0.91254
120	1.66135	0.96889
142	1.71008	0.98862
160	1.73269	1.00456
180	1.6737	0.97356
203	1.83949	1.08493
220	1.82588	1.10208
240	1.73382	1.04551

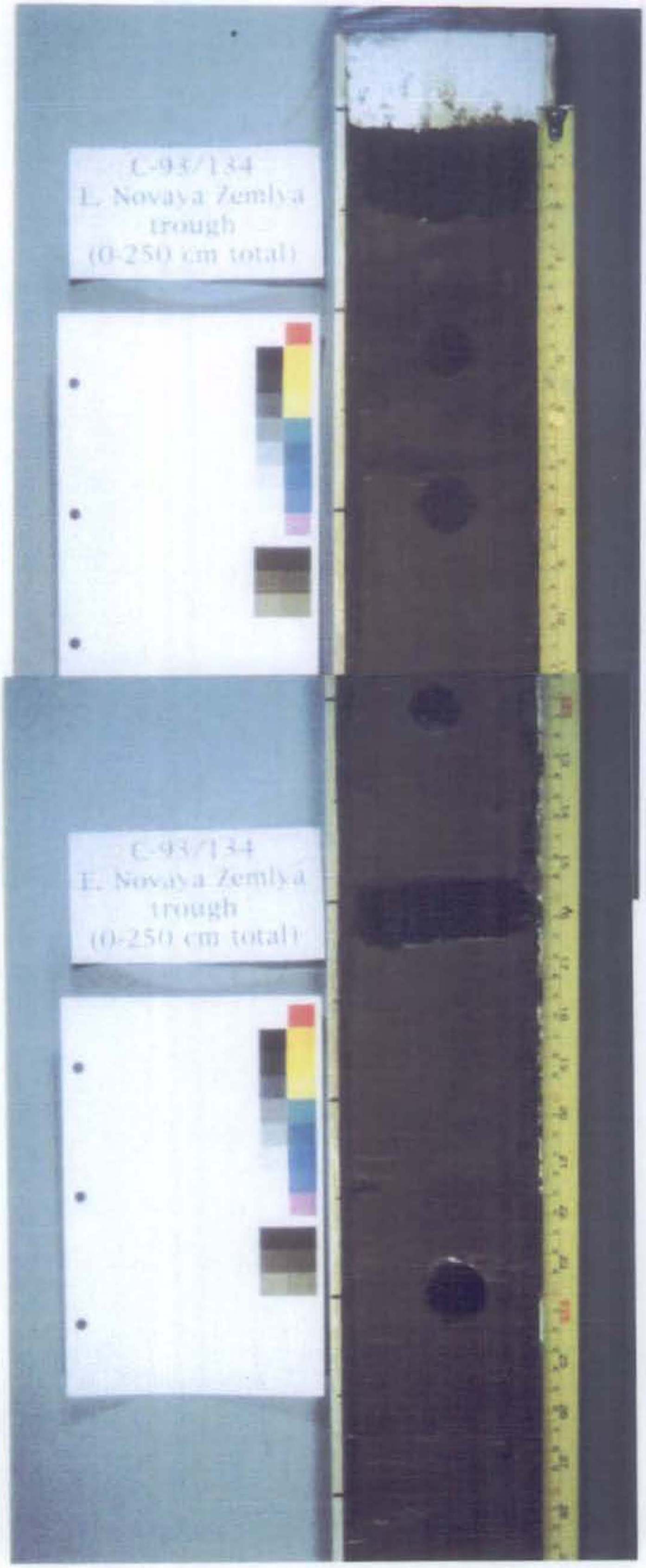
	Unit 1A	Unit 1B
average wet density	1.69	1.8
standard deviation	0.11	0
average dry density	0.93	1.16
standard deviation	0.1	0

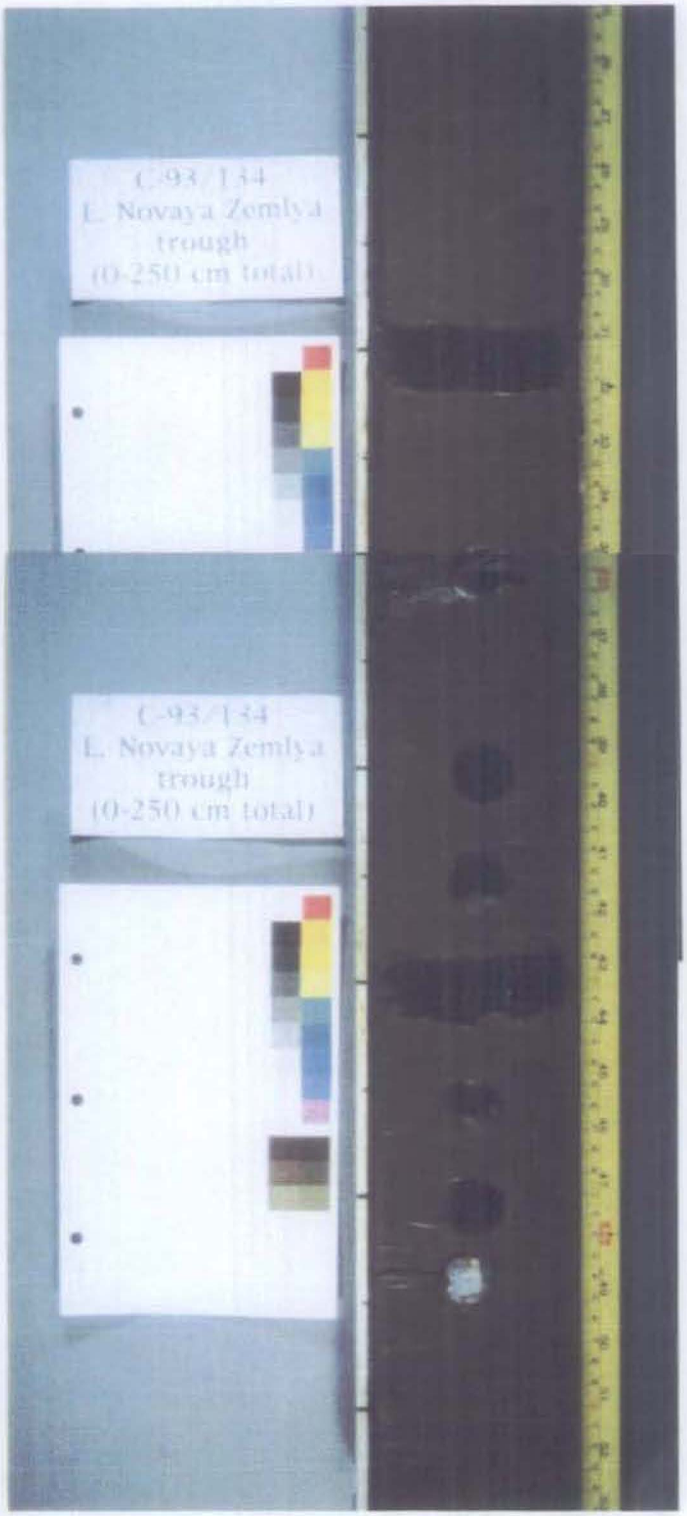
Table 3 **Sand, Silt and Clay Percentages**

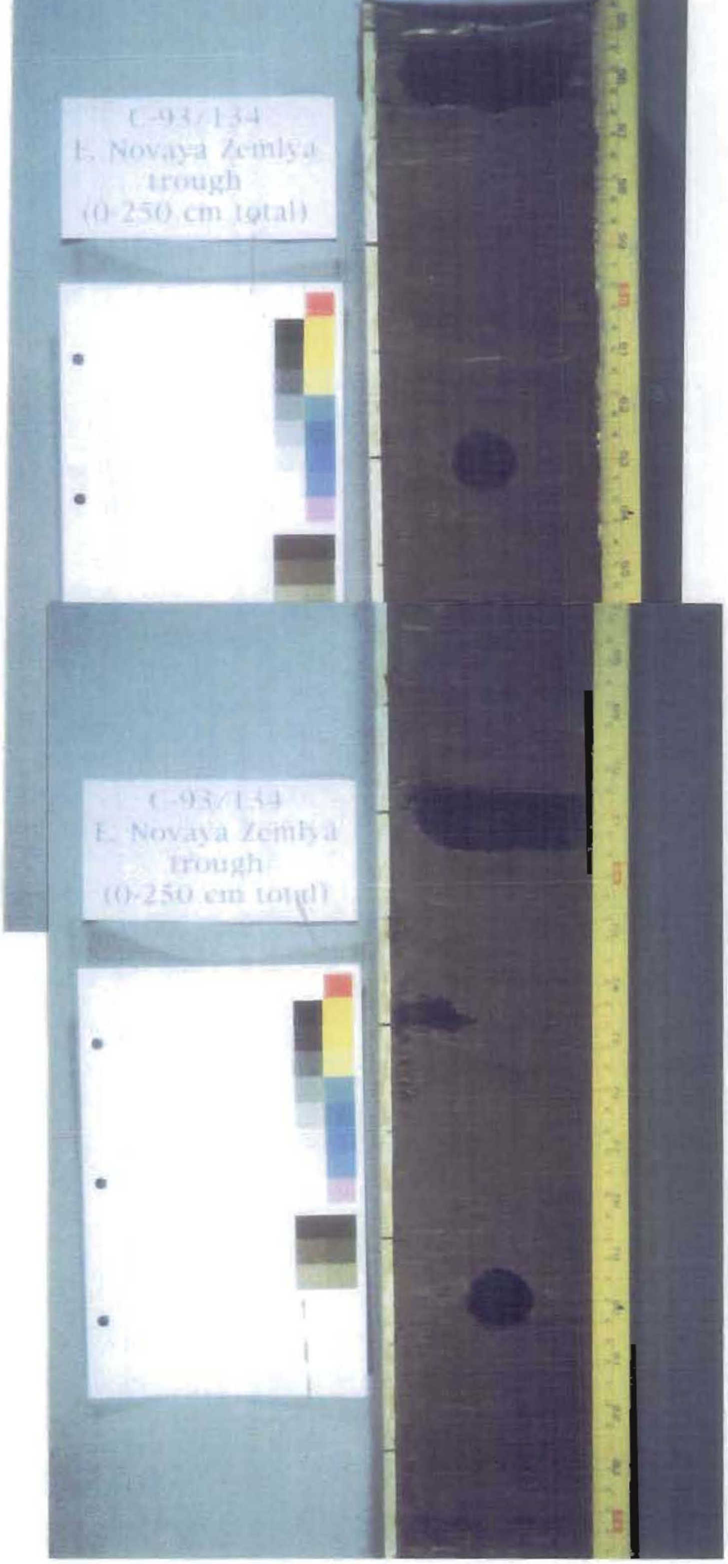
interval depth	percent sand	percent silt	percent clay	unit
3.50	7.87	38.74	53.39	1A
12.00	13.12	48.50	38.44	1A
20.00	8.69	53.24	38.07	1A
30.00	4.87	44.47	50.66	1A
40.00	6.28	42.77	50.95	1A
60.00	7.93	35.62	56.45	1A
80.00	10.20	41.11	48.70	1A
90.00	13.52	37.48	48.96	1A
100.00	7.12	31.57	61.31	1A
105.00	8.43	34.41	57.12	1A
110.00	46.22	30.40	23.39	1B
115.00	8.95	37.77	53.27	1A
120.00	17.68	31.41	50.90	1A
142.00	8.96	32.75	58.16	1A
160.00	12.90	32.60	54.50	1A
180.00	13.32	32.33	54.35	1A
203.00	12.28	29.25	58.47	1A
220.00	15.06	31.51	53.43	1A
240.00	11.42	36.57	52.01	1A

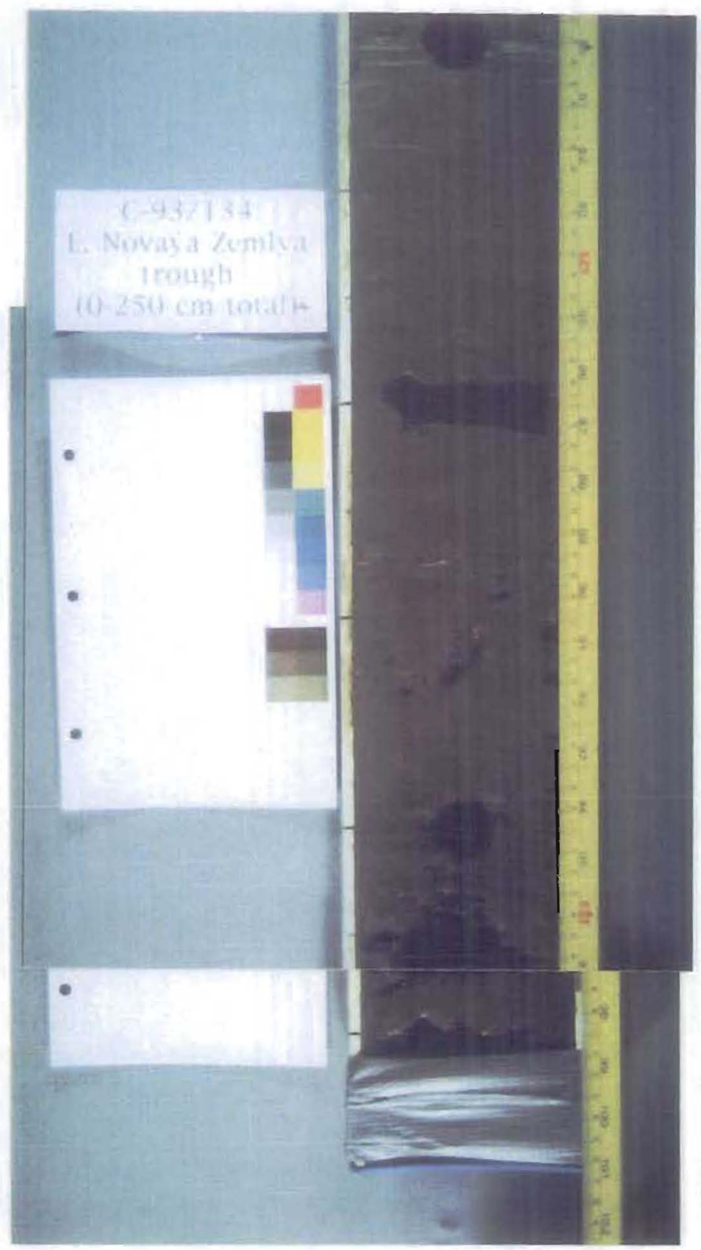
	sand	silt	clay
average	10.5	37.3	52.2
standard deviation	3.4	6.5	6.1

Appendix Pictures of C-93/134 taken 2/95






C-93/134
E. Novaya Zemlya
trough
(0-250 cm total)
C-93/134
E. Novaya Zemlya
trough
(0-250 cm total)


C-93/134
E. Novaya Zemlya
trough
(0-250 cm total)